



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(21) International Application Number: PCT/GB99/02694 (22) International Filing Date: 13 August 1999 (13.08.1999) (30) Priority Data: 09/133,747 13 August 1998 (13.08.1998) US (60) Parent Application or Grant PES INC. [/]; (). PETROLEUM ENGINEERING SERVICES LIMITED [/]; (). BOULDIN, Brett [/]; (). PURKIS, Dan [/]; (). BOULDIN, Brett [/]; (). PURKIS, Dan [/]; (). MURGITROYD & COMPANY ; ().		Published
(54) Title: HYDRAULIC WELL CONTROL SYSTEM (54) Titre: SYSTEME HYDRAULIQUE DE COMMANDE D'UN PUIT (57) Abstract <p>A system for transmitting hydraulic control signals and hydraulic power to downhole well tools while reducing the number of hydraulic lines installed in the wellbore. Hydraulic control signals can be furnished at relatively lower pressures, and the hydraulic pressure within the line can be selectively increased over a threshold level to provide hydraulic actuation power. The system can provide multiple control paths through a few number of hydraulic lines to provide flexibility and verification of well tool operation. Closed loop hydraulic operation monitors well tool operation, and a combination of pressurized hydraulic lines can provide an operating code for selective downhole well tool control. Four hydraulic lines can provide independent control and actuation of seven well tools, and additional combinations can be constructed.</p> (57) Abrégé <p>L'invention concerne un système de transmission de signaux de commande hydraulique et d'énergie hydraulique vers des outils fond de trou d'un puits, ce système permettant de réduire le nombre de canalisations hydrauliques installées dans le trou de forage. Des signaux de commande hydraulique peuvent être fournis à des pressions relativement basses, la pression hydraulique régnant dans la canalisation pouvant être augmentée de manière sélective pour être portée au-dessus d'un niveau de seuil, afin d' fournir une énergie de commande hydraulique. Ce système autorise la constitution de plusieurs trajets de commande à travers un nombre réduit de canalisations hydrauliques, pour permettre la flexibilité et la vérification du fonctionnement des outils fond de trou. Le fonctionnement hydraulique en boucle fermée permet de surveiller le fonctionnement des outils fond de trou, et une combinaison des canalisations hydrauliques sous pression permet d'obtenir un code de fonctionnement destiné à la commande sélective des outils fond de trou. Quatre canalisations hydrauliques peuvent assurer une commande et un fonctionnement indépendants de sept outils fond de trou, des combinaisons supplémentaires pouvant être agencées.</p>		

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(54) Title: HYDRAULIC WELL CONTROL SYSTEM			
<p>The diagram illustrates a hydraulic well control system. It features three parallel hydraulic circuits, labeled 22, 24, and 26. Each circuit consists of a valve (001, 010, 011, 100, 101, 110) and a well tool (22, 24, 26). The valves are connected to a common manifold (28) via lines 30 and 32. The manifold (28) is connected to the well tools (22, 24, 26) via lines 30 and 32. The diagram shows the flow of hydraulic fluid from the manifold (28) through the valves and lines to the well tools (22, 24, 26).</p>			
(57) Abstract			
<p>A system for transmitting hydraulic control signals and hydraulic power to downhole well tools while reducing the number of hydraulic lines installed in the wellbore. Hydraulic control signals can be furnished at relatively lower pressures, and the hydraulic pressure within the line can be selectively increased over a threshold level to provide hydraulic actuation power. The system can provide multiple control paths through a few number of hydraulic lines to provide flexibility and verification of well tool operation. Closed loop hydraulic operation monitors well tool operation, and a combination of pressurized hydraulic lines can provide an operating code for selective downhole well tool control. Four hydraulic lines can provide independent control and actuation of seven well tools, and additional combinations can be constructed.</p>			

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Description

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HYDRAULIC WELL CONTROL SYSTEM

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BACKGROUND OF THE INVENTION

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The present invention relates to a system for controlling the production of hydrocarbons and other fluids from downhole wells. More particularly, the invention relates to a system for providing hydraulic control signals and power through the same hydraulic line, and for providing integrated control of multiple well tools with a minimal number of hydraulic lines.

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Various tools and tool systems have been developed to control, select or regulate the production of hydrocarbon fluids and other fluids produced downhole from subterranean wells. Downhole well tools such as sliding sleeves, sliding side doors, interval control lines, safety valves, lubricator valves, and gas lift valves are representative examples of control tools positioned downhole in wells.

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Sliding sleeves and similar devices can be placed in isolated sections of the wellbore to control fluid flow from such wellbore section. Multiple sliding sleeves and interval control valves (ICVs) can be placed in different isolated sections within production tubing to jointly control fluid flow within the particular production tubing section, and to commingle

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1 the various fluids within the common production tubing
2 interior. This production method is known as
3 "comingling" or "coproduction". Reverse circulation
4 of fluids through the production of tubing, known as
5 "injection splitting", is performed by pumping a
6 production chemical or other fluid downwardly into the
7 production tubing and through different production
8 tubing sections.

9 Wellbore tool actuators generally comprise short
10 term or long term devices. Short term devices include
11 one shot tools and tool having limited operating
12 cycles. Long term devices can use hydraulically
13 operated mechanical mechanisms performing over multiple
14 cycles. Actuation signals are provided through
15 mechanical, direct pressure, pressure pulsing,
16 electrical, electromagnetic, acoustic, and other
17 mechanisms. The control mechanism may involve simple
18 mechanics, fluid logic controls, timers, or
19 electronics. Motive power to actuated the tools can be
20 provided through springs, differential pressure,
21 hydrostatic pressure, or locally generated power.

22 Long term devices provide virtually unlimited
23 operating cycles and are designed for operation through
24 the well producing life. One long term safety valve
25 device provides fail safe operating capabilities which
26 closes the tubing interior with spring powered force
27 when the hydraulic line pressure is lost. Combination
28 electrical and hydraulic powered systems have been
29 developed for downhole use, and other systems include
30 sensors which verify proper operation of tool
31 components.

32 Interval control valve (ICV) activation is
33 typically accomplished with mechanical techniques such
34 as a shifting tool deployed from the well surface on a
35 workstring or coiled tubing. This technique is
36 expensive and inefficient because the surface

1 controlled rigs may be unavailable, advance logistical
2 planning is required, and hydrocarbon production is
3 lost during operation of the shifting tool.

4 Alternatively, electrical and hydraulic umbilical lines
5 have been used to remotely control one or more ICVs
6 without reentry to the wellbore.

7 Control for one downhole tool can be hydraulically
8 accomplished by connecting a single hydraulic line to a
9 tool such as an ICV or a lubricator valve, and by
10 discharging hydraulic fluid from the line end into the
11 wellbore. This technique has several limitations as
12 the hydraulic fluid exits the wellbore because of
13 differential pressures between the hydraulic line and
14 the wellbore. Additionally, the setting depths are
15 limited by the maximum pressure that a pressure relief
16 valve can hold between the differential pressure
17 between the control line pressure and the production
18 tubing when the system is at rest. These limitations
19 restrict single line hydraulics to low differential
20 pressure applications such as lubricator valves and ESP
21 sliding sleeves. Further, discharge of hydraulic fluid
22 into the wellbore comprises an environmental discharge
23 and risks backflow and particulate contamination into
24 the hydraulic system. To avoid such contamination and
25 corrosion problems, closed loop hydraulic systems are
26 preferred over hydraulic fluid discharge valves
27 downstream of the well tool actuator.

28 Certain techniques have proposed multiple tool
29 operation through a single hydraulic line. United
30 States Patent No 4,660,647 to Richart (1987) disclosed
31 a system for changing downhole flow paths by providing
32 different plug assemblies suitable for insertion within
33 a side pocket mandrel downhole in the wellbore. In
34 United States Patent No. 4,796,699 to Upchurch (1989),
35 an electronic downhole controller received pulsed
36 signals for further operation of multiple well tools.

1 In United States Patent No. 4,942,926 to Lessi (1990),
2 hydraulic fluid pressure from a single line was
3 directed by solenoid valves to control different
4 operations. A return means in the form of a spring
5 facilitated return of the components to the original
6 position. A second hydraulic line was added to provide
7 for dual operation of the same tool function by
8 controlling hydraulic fluid flow in different
9 directions. Similarly, United States Patent No.
10 4,945,995 to Thulance et al. (1990) disclosed an
11 electrically operated solenoid valve for selectively
12 controlling operation of a hydraulic line for opening
13 downhole wellbore valves.

14 Other downhole well tools use two hydraulic lines
15 to control a single tool. In United States Patent No.
16 3,906,726 to Jameson (1975), a manual control disable
17 valve and a manual choke control valve controlled the
18 flow of hydraulic fluid on either side of a piston
19 head. In United States Patent Nos. 4,197,879 to Young
20 (1980), and in 4,368, 871 to Young (1983), two
21 hydraulic hoses controlled from a vessel were
22 selectively pressurized to open and close a lubricator
23 valve during well test operations. A separate control
24 fluid was directed by each hydraulic hose so that one
25 fluid pressure opened the valve and a different fluid
26 pressure closed the valve. In United States Patent No
27 4,476,933 to Brooks (1984), a piston shoulder
28 functioned as a double acting piston in a lubricator
29 valve, and two separate control lines were connected to
30 conduits and to conventional fittings to provide high
31 or low pressures in chambers on opposite sides of the
32 piston shoulder. In United States Patent No. 4,522,370
33 to Noack et al. (1985), a combined lubricator and
34 retainer valve was operable with first and second
35 pressure fluids and pressure responsive members, and
36 two control lines provided two hydraulic fluid

1 pressures to the control valve. This technique is
2 inefficient because two hydraulic lines are required
3 for each downhole tool, which magnifies the problems
4 associated with hydraulic lines run through packers and
5 wellheads.

6 Instead of multiple hydraulic lines, other
7 techniques have attempted to establish an operating
8 sequence. In United States Patent No. 5,065,825 to
9 Bardin et al. (1991), a solenoid valve was operated in
10 response to a predetermined sequence to move fluid from
11 one position to another. A check valve permitted
12 discharge of oil into a reservoir to replenish the
13 reservoir oil pressure. Other systems use electronic
14 controllers downhole in the wellbore to distribute,
15 however the electronics are susceptible to temperature
16 induced deterioration and other reliability problems.

17 Multiple hydraulic lines downhole in a wellbore
18 can extend for thousands of feet into the wellbore. In
19 large wellbores having different production zones and
20 multiple tool requirements, large numbers of hydraulic
21 lines are required. Each line significantly increases
22 installation cost and the number of components
23 potentially subject to failure. Accordingly, a need
24 exists for an improved well control system capable of
25 avoiding the limitations of prior art devices. The
26 system should be reliable, should be adaptable to
27 different tool configurations and combinations, and
28 should be inexpensive to deploy.

29 SUMMARY OF THE INVENTION

31 The present invention provides an apparatus and
32 system for transmitting pressurized fluid between a
33 wellbore surface and a well tool located downhole in
34 the wellbore. The apparatus comprises at least two
35 hydraulic lines engaged with the well tool for
36 conveying said fluid to the well tool, and means for

1 pressurizing the fluid within the hydraulic lines. The
2 hydraulic lines are capable of providing communication
3 control signals to the well tool are further capable of
4 providing fluid pressure to actuate the well tool. In
5 different embodiments of the invention, at least three
6 hydraulic lines are each engaged with each well tool
7 for selectively conveying the fluid to each well tool,
8 and hydraulic control means engaged between said
9 hydraulic lines and each well tool for selectively
10 controlling actuation of each well tool in response to
11 pressure changes within selected hydraulic lines.

12 The invention also provides a system for
13 controlling at least three well tools located downhole
14 in a wellbore. The system comprises hydraulic pressure
15 means for selectively pressurizing a fluid, at least
16 two hydraulic lines engaged with the hydraulic pressure
17 means and with each well tool for selectively conveying
18 fluid pressure to each well tool, and hydraulic control
19 means engaged between each hydraulic line and each well
20 tool. Each hydraulic control means is operable in
21 response to selective pressurization of one or more
22 hydraulic lines by said hydraulic pressure means, and
23 operation of a well tool through the pressurization of
24 one hydraulic line displaces fluid which is conveyed
25 through another hydraulic line.

26 BRIEF DESCRIPTION OF THE DRAWINGS

27 Figure 1 illustrates a two hydraulic line system
28 for providing hydraulic pressure control and power to
29 well tools.
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31 Figure 2 illustrates a graph showing a hydraulic
32 line pressure code for providing hydraulic control and
33 power capabilities through the same hydraulic line.
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35 Figure 3 illustrates a three well tool and three
36 hydraulic line apparatus.

 Figure 4 shows a representative control code for

1 the apparatus shown in Figure 3.

2 Figure 5 illustrates a seven well tool and four
3 hydraulic line system for providing selective well
4 control and power.

5 Figure 6 illustrates a representative control code
6 for the system shown in Figure 5.

7 Figure 7 illustrates another seven well tool and
8 four hydraulic line system.

9 10 DESCRIPTION OF THE PREFERRED EMBODIMENTS

11 The invention provides hydraulic fluid control for
12 downhole well tools by uniquely utilizing hydraulics
13 with logic circuitry. Such logic circuitry is
14 analogous to electrical and electronics systems, and
15 depends on Boolean Logic using "AND" and "OR" gates in
16 the form of hydraulic switches. Using this unique
17 concept, digital control capability, or "digital-
18 hydraulics" can be adapted to the control of downhole
19 well tools such as ICVs.

20 Figure 1 illustrates two hydraulic lines 10 and 12
21 engaged with pump 14 for providing hydraulic pressure
22 to fluid (not shown) in lines 10 and 12. Lines 10 and
23 12 are further engaged with downhole well tools 16 and
24 18 for providing hydraulic fluid pressure to tools 16
25 and 18. Pump 14 can comprise a controller for
26 selectively controlling the fluid pressure within lines
27 10 and 12, and can cooperate with a hydraulic control
28 means such as valve 20 located downhole in the wellbore
29 in engagement with lines 10 and 12, and with tools 16
30 and 18. Selectively control over the distribution of
31 hydraulic fluid pressure can be furnished and
32 controlled with pump 14 at the wellbore surface, or
33 with valve 20 downhole in the wellbore. Control
34 signals to tools 16 and 18 and valve 20 can be provided
35 within a different pressure range as that required for
36 actuation of tools 16 and 18, and the ranges can be

1 higher, lower, or overlapping.

2 Figure 2 illustrates one combination of
3 communication and power functions through the same
4 hydraulic tubing, conduit, passage or line such as line
5 10 wherein the control signals are provided at lower
6 pressures than the power actuation pressures. Pressure
7 is plotted against time, and the hydraulic pressure is
8 initially raised above the communication threshold but
9 below the power threshold. Within this pressure range,
10 communication signals and controls can be performed
11 through the hydraulic line. The line pressure is
12 raised to a selected level so that subsequent powering
13 up of the hydraulic line pressure raises the line
14 pressure to a certain level. Subsequent actuation of
15 the well control devices, normally delayed as the
16 pressure builds up within the long hydraulic tubing,
17 occurs at a faster rate because the line is already
18 pressurized to a certain level.

19 The invention further permits the use of
20 additional hydraulic lines and combinations of
21 hydraulic lines and controllers to provide a
22 hydraulically actuated well control and power system.
23 One embodiment of the invention is based on the concept
24 that a selected number of hydraulic control lines could
25 be engaged with a tool and that control line
26 combinations can be used for different purposes. For
27 example, a three control line system could use a first
28 line for hydraulic power such as moving a hydraulic
29 cylinder, a second line to provide a return path for
30 returning fluid to the initial location, and all three
31 lines for providing digital-hydraulic code
32 capabilities. Such code can be represented by the
33 following Table:

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Hydraulic Lines	Digital Equation			Numeric Value Lines	
#1	#2	#3			
0	0	0	$0 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$	=	0
0	0	1	$0 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$	=	1
0	1	0	$0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$	=	2
0	1	1	$0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$	=	3
1	0	0	$1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$	=	4
1	0	1	$1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$	=	5
1	1	0	$1 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$	=	6
1	1	1	$1 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$	=	7

If "1" represents a pressurized line and if "0" represents an unpressurized line, then the combination of hydraulic lines provides the described code format for a binary communication code. Because the hydraulic line operation can use both a pressurized and an unpressurized line in a preferred embodiment of the invention, codes 000 and 111 would not be used in this embodiment. However, if one or more lines discharged fluid to the outside of the line to the tubing exterior, another tool, or other location, codes 000 and 111 would be useful for transmitting power or signals. If codes 000 and 111 are excluded from use in the inventive embodiment described, the following six codes are available for tool control:

#1	#2	#3		
0	0	1	-	1
0	1	0	-	2
0	1	1	-	3
1	0	0	-	4
1	0	1	-	5
1	1	0	-	6

These codes are unique and can be grouped to provide six independent degrees of freedom to a hydraulic network. Different combinations are possible, and one combination permits the operation of

1 three well tools such as ICVs 22, 24, and 26 having
 2 double actuated floating pistons as illustrated in
 3 Figure 3. Lines 28, 30 and 32 are engaged between
 4 pump 14 and ICVs 22, 24, and 26. Lines 28, 30, and 32
 5 could provide an opening code 001 for ICV 22. After a
 6 sufficient time lapse for all well tools such as the
 7 ICVs has occurred to detect and register the 001 code,
 8 the line pressure can be raised above the power
 9 threshold until a selected pressure level is achieved.
 10 The pressure can be held constant at such level, or
 11 varied to accomplish other functions. The selected
 12 well tool such as ICV 22 is actuated, and return fluid
 13 is directed back through one or more of the lines
 14 designated as a "0", unpressurized line. Next, control
 15 line 32 is bled to zero and the entire system is at
 16 rest, leaving ICV 22 fully open until further
 17 operation. To open ICV 24, control linesw 28, 30, and
 18 32 can be coded and operated as illustrated. After
 19 sufficient time has passed, the system pressure can be
 20 increased to operate ICV 24. The degrees of control
 21 freedom and operating controls can be represented by
 22 the following instructions:

23
24 Hydraulic Line Number

	<u>28</u>	<u>30</u>	<u>32</u>	
26	0	0	1	Open ICV 22
27	0	1	0	Close ICV 22
28	0	1	1	Open ICV 24
29	1	0	0	Close ICV 24
30	1	0	1	Open ICV 26
31	1	1	0	Close ICV 26

32
 33 $X = \frac{2^N - 2}{2}$, and $X = \frac{2^3 - 2}{2} = 3$ control lines
 34

35 where

36 X equals the number of independently controlled

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1 ICVs, and
 2 N equals the number of control lines.

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4 Another combination is expressed below wherein
 5 additional ICVs 34 and 36 are added to build a five
 6 well tool system.

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8 Hydraulic Line Number

9 28 30 32

10 0 0 1 All ICVs Open

11 0 1 0 Close ICV 22

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12 0 1 1 Close ICV 24

13 1 0 0 Close ICV 26

14 1 0 1 Close ICV 34

15 1 1 0 Close ICV 36

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17 $Z = 2^N - 3$, and $Z = 2^3 - 3 = 5$ control lines

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19 where

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20 Z equals the number of dependently controlled ICVs, and
 21 N equals the number of control lines.

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23 The number of independently and dependently
 24 controlled ICVs provides system flexibility in the
 25 design of an operating system. For example,

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28 # of Control Lines # of Independent ICVs # of Dependent ICVs

29

30 N $X = \frac{2^N - 2}{2}$ $Z = 2^N - 3$

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33	1	0	0
34	2	1	1
35	3	3	5
36	4	7	13
37	5	15	27
38	6	31	61

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1	7	63	125
2	8	127	253

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From this chart, the feasibility of the concept for one or two hydraulic lines does not offer significant control flexibility over single, dedicated hydraulic lines. At three control lines and greater, the benefits of the digital-hydraulic system become apparent as significant combinations of well control functions are available. For the majority of conventional downhole well uses, four control lines are adequate. However, the concepts taught by the invention provide additionally design flexibility to accommodate additional requirements as indicated.

A four ICV digital-hydraulic control system having seven independent devices and thirteen dependant devices can operate as follows:

Hydraulic Line Number

#1	#2	#3	#4	Independent	Dependent
0	0	0	1	Open ICV#1	All ICVs open
0	0	1	0	Close ICV#1	Close ICV#1
0	0	1	1	Open ICV#2	Close ICV#2
0	1	0	0	Close ICV#2	Close ICV#3
0	1	0	1	Open ICV#3	Close ICV#4
0	1	1	0	Close ICV#3	Close ICV#5
0	1	1	1	Open ICV#4	Close ICV#6
1	0	0	0	Close ICV#4	Close ICV#7
1	0	0	1	Open ICV#5	Close ICV#8
1	0	1	0	Close ICV#5	Close ICV#9
1	0	1	1	Open ICV#6	Close ICV#10
1	1	0	0	Close ICV#6	Close ICV#11
1	1	0	1	Open ICV#7	Close ICV#12
1	1	1	0	Close ICV#7	Close ICV#13

A representative embodiment of a four hydraulic

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line system is illustrated in Figure 5 wherein
hydraulic lines 40, 42, 44 and 46 are engaged with
controller 48, and are further engaged with hydraulic
control means such as module 50 connected to tool 52,
module 54 connected to tool 56, module 58 connected to
tool 60, module 62 connected to tool 64, module 66
connected to tool 68, module 70 connected to tool 72,
and module 74 connected to tool 76. Selective
pressurization of lines 40, 42, 44 and 46 selectively
operates one or more of such seven well tools according
to a programmed code as represented in Figure 6. For
example, a code of "0010", wherein all lines are
unpressurized except for the pressurization of line 44,
operates to close tool 52 as illustrated.

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Each hydraulic control means or control mechanism
can be designed with a combination of valves and other
components to perform a desired function. Referring to
Figure 3, control mechanism 78 includes two control
modules 80 and 82 each located on opposite sides of the
floating piston within ICV 22. Control module 80
includes check valve engaged with line 32, and further
includes check valve 84 engaged with pilot operated
valves 86 and 88. Pilot operated valve 86 is engaged
with line 30, and pilot operated valve 88 is engaged
with line 28. Check valves 90 and 92 and pilot
operated valves 94 and 96 are positioned as shown in
Figure 3 for control module 82. Similar combinations
of modules and internal components are illustrated in
Figure 5 and in Figure 7 for different operating
characteristics.

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The unique combination of valves and other
components within each control module provides for
unique, selected operating functions and
characteristics. Depending on the proper sequence and
configuration, pressurization of a hydraulic line can
actuate one of the tools without actuating other tools

1 in the system. Alternatively, various combinations of
2 well tools could be actuated with the same hydraulic
3 line if desired.

4 By providing communication and power capabilities
5 through the same hydraulic lines, the invention
6 significantly eliminates problems associated with
7 pressure transients. In deep wellbores, the hydraulic
8 lines are very long and slender, which greatly affects
9 the hydraulic line ability to quickly transmit pressure
10 pulses or changes from the wellbore surface to a
11 downhole tool location. In deep wellbores, five to ten
12 minutes could be required before the hydraulic lines
13 were accurately coded for the communication of
14 sequenced controls. If some of the ICVs were located
15 relatively shallow in the wellbore, such ICVs would
16 receive the code long before other ICVs located deep in
17 the wellbore. This configuration could cause confusion
18 on the digital-hydraulics control circuit.

19 This problem can be resolved by dedicating certain
20 lines for communication signals and other lines for
21 power. Alternatively, a preferred embodiment of the
22 invention utilizes such time delay characteristics by
23 applying the communication coding early at relatively
24 low pressures where the ICVs receive the codes but are
25 not activated, and then the pressure is increased above
26 a selected activation threshold to move the ICVs. This
27 permits communication and power to be transmitted
28 through the same hydraulic lines, and further uses the
29 communication pressures to initially raise the line
30 pressures to a selected level and to shorten the power
31 up time required.

32 For another instruction, pistons within an ICV can
33 be moved in a direction from the initial position
34 toward a second position, and can be maintained above
35 second position pressure. The device response
36 initially directs the control line pressure to the

second side of the piston actuator. As the piston responds to the force created by the differential pressure, fluid on the low pressure side is displaced into the tubing. The device eventually strokes fully and attains the second position, and the fluid will slowly bleed away.

Another embodiment of the invention is illustrated below where certain lines are dedicated as power lines and other lines are dedicated as communication control lines. A representative sequence code for a five line tool system can be expressed as follows:

<u>Power Lines</u>		<u>Communication Lines</u>			<u>Independent</u>	<u>Dependent</u>
#1	#2	A	B	C		
0	1	0	0	0	Open ICV#1	All ICVs closed
1	0	0	0	0	Close ICV#1	Open ICV#1
0	1	0	0	1	Open ICV#2	Open ICV#2
1	0	0	0	1	Close ICV#2	Open ICV#3
0	1	0	1	0	Open ICV#3	Open ICV#4
1	0	0	1	0	Close ICV#3	Open ICV#5
0	1	0	1	1	Open ICV#4	Open ICV#6
1	0	0	1	1	Close ICV#4	Open ICV#7
0	1	1	0	0	Open ICV#5	Open ICV#8
1	0	1	0	0	Close ICV#5	Open ICV#9
0	1	1	0	1	Open ICV#6	Open ICV#10
1	0	1	0	1	Close ICV#6	Open ICV#11
0	1	1	1	0	Open ICV#7	Open ICV#12
1	0	1	1	0	Close ICV#7	Open ICV#13
0	1	1	1	1	Open ICV#8	Open ICV#14
1	0	1	1	1	<u>Close ICV#8</u>	<u>Open ICV#15</u>

5 Lines, 8 ICVs 5 Lines, 15 ICVs

Although more lines are required to control a certain number of well tools, this embodiment of the invention provides certain design benefits. Response time within the lines can be faster, a single pressure level can be utilized, and any possibility of confusion between a communication pressure code and a power pressure code is eliminated.

The invention is applicable to many different

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1 tools including downhole devices having more than one
2 operating mode or position from a single dedicated
3 hydraulic line. Such tools include tubing mounted
4 ball valves, sliding sleeves, lubricator valves, and
5 other devices. The invention is particularly suitable
6 for devices having a two-way piston, open/close
7 actuator for providing force in either direction in
8 response to differential pressure across the piston.

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The operating codes described above can be
designed to provide a static operating code where the
fluid pressures stabilize within each hydraulic line.
By providing for static pressures at different levels,
communication control signals can be provided by the
presence or absence of fluid pressure, or by the fluid
pressure level observed. For example, different
pressure levels through one or more lines can generate
different system combinations far in excess of the "0"
and "1" combinations stated above, and can provide for
multiple combinations at least three or four times
greater. In effect, a higher order of combinations is
possible by using different line pressures in
combination with different hydraulic lines.
Alternatively, the operation of a single line can be
pulsed in cooperation with a well tool or a hydraulic
control means operation, or can be pulsed in
combination with two or more hydraulic lines to achieve
additional control sequences. Such pulsing techniques
further increase the number of system combinations
available through a relatively few number of hydraulic
lines, thereby providing maximum system capabilities
with a minimum number of hydraulic lines.

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Although the preferred embodiment of the invention
permits hydraulic switching of the lines for operation
of downhole well tools such as ICVs, switching
functions could be performed with various switch
techniques including electrical, electromechanical,

1 acoustic, mechanical, and other forms of switches. The
2 digital hydraulic logic described by the invention is
3 applicable to different combinations of conventional
4 and unconventional switches and tools, and provides the
5 benefit of significantly increasing system reliability
6 and of permitting a reduction in the number of
7 hydraulic lines run downhole in the wellbore.

8 The invention permits operating forces in the
9 range above 10,000 lb. and is capable of driving
10 devices in different directions. Such high driving
11 forces provide for reliable operation where
12 environmental conditions causing scale and corrosion
13 increase frictional forces over time. Such high
14 driving forces also provide for lower pressure
15 communication ranges suitable for providing various
16 control operations and sequences.

17 The invention controls a large number of downhole
18 well tools while minimizing the number of control lines
19 extending between the tools and the wellbore surface.
20 A subsurface safety barrier is provided to reduce the
21 number of undesirable returns through the hydraulic
22 lines, and high activation forces are provided in dual
23 directions. The system is expandable to support
24 additional high resolution devices, can support fail
25 safe equipment, and can provide single command control
26 or multiple control commands. The invention is
27 operable with pressure or no pressure conditions, can
28 operate as a closed loop or open loop system, and is
29 adaptable to conventional control panel operations. As
30 an open loop system, hydraulic fluid can be exhausted
31 from one or more lines or well tools if return of the
32 hydraulic fluid is not necessary to the wellbore
33 application. The invention can further be run in
34 parallel with other downhole wellbore power and control
35 systems. Accordingly, the invention is particularly
36 useful in wellbores having multiple zones or connected

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1 branch wellbores such as in multilateral wellbores.
2 Although the invention has been described in terms
3 of certain preferred embodiments, it will become
4 apparent to those of ordinary skill in the art that
5 modifications and improvements can be made to the
6 inventive concepts herein without departing from the
7 scope of the invention. The embodiments shown herein
8 are merely illustrative of the inventive concepts and
9 should not be interpreted as limiting the scope of the
10 invention.

Claims

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1 WHAT IS CLAIMED IS:

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3 1. An apparatus for transmitting pressurized fluid
4 between a wellbore surface and a well tool located
5 downhole in the wellbore, comprising:

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6 at least two hydraulic lines engaged with the well
7 tool for conveying said fluid to the well tool, wherein
8 said hydraulic lines are capable of providing
9 communication control signals to the well tool, and
10 wherein said hydraulic lines are further capable of
11 providing fluid pressure to actuate the well tool; and

20

12 means for pressurizing the fluid within said
13 hydraulic lines to provide said communication signals
14 and said fluid actuation pressure.

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16 2. An apparatus as recited in Claim 1, further
17 comprising a controller at the wellbore surface for
18 selectively pressurizing said hydraulic lines.

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20 3. An apparatus as recited in either Claim 1 or Claim
21 2, wherein said communication control signals comprise
22 a lower pressure than said fluid pressure for actuating
23 the well tool.

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25 4. An apparatus as recited in any preceding Claim,
26 wherein said communication control signals are provided
27 in a pulsed sequence.

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29 5. An apparatus as recited in any preceding Claim,
30 wherein said communication control signals are provided
31 in a static code identified by the presence of a
32 selected fluid pressure.

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34 6. An apparatus as recited in any preceding Claim,
35 wherein at least three well tools are each engaged with
36 two or more hydraulic lines, further comprising a

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1 switch engaged with said hydraulic lines and said well
2 tools for actuating one of the well tools by the
3 selective pressurization of one hydraulic line.

4
5 7. An apparatus as recited in any preceding Claim,
6 wherein at least three well tools are each engaged with
7 two or more hydraulic lines, further comprising a
8 switch engaged with said hydraulic lines and said well
9 tools for actuating one of the well tools by the
10 selective pressurization of two hydraulic lines.

11
12 8. An apparatus as recited in any preceding Claim,
13 wherein said hydraulic lines are capable of providing
14 well tool actuation pressure, after communication
15 control signals are transmitted to the well tool, by
16 increasing the fluid pressure in at least one hydraulic
17 line.

18
19 9. An apparatus as recited in any preceding Claim,
20 wherein said hydraulic lines form a closed loop for
21 returning fluid to the wellbore surface, further
22 comprising means for detecting the return of fluid
23 through one hydraulic line when another hydraulic line
24 is pressurized.

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26 10. An apparatus as recited in any preceding Claim,
27 wherein one of said lines is dedicated to provide
28 communication control signals.

29
30 11. An apparatus as recited in any preceding Claim,
31 wherein one of said lines is dedicated to provide fluid
32 pressure to actuate the well tool.

33
34 12. An apparatus for transmitting pressurized fluid
35 between a wellbore surface and three well tools located
36 downhole in the wellbore, comprising:

1 at least three hydraulic lines each engaged with
2 each well tool for selectively conveying the fluid to
3 each well tool; and

4 control means engaged between said hydraulic lines
5 and each well tool for selectively controlling
6 actuation of each well tool in response to pressure
7 changes within selected hydraulic lines.

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9 13. An apparatus as recited in Claim 12, wherein said
10 control means comprises a hydraulic control means.

11
12 14. An apparatus as recited in either Claim 12 or
13 Claim 13, wherein the well tools are actuatable in two
14 directions from opposing positions of the well tool,
15 and wherein said control means comprises two control
16 modules separately engaged with said opposing well tool
17 positions so that each control module is capable of
18 providing selective fluid flow in two directions
19 relative to the well tool.

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21 15. An apparatus as recited in Claim 14, wherein each
22 control module comprises a hydraulic circuit having a
23 check valve for resisting fluid flow from the tool
24 direction and in communication with one of said
25 hydraulic lines, and further comprises a pilot operated
26 valve engaged with said hydraulic line and with the
27 tool which is closed in an initial condition and is
28 actuatable by a fluid pressure increase in one of said
29 other hydraulic lines.

30
31 16. An apparatus as recited in Claim 15, further
32 comprising another pilot operated valve engaged with
33 said hydraulic line and with the tool which is closed
34 in an initial condition and is actuatable by a fluid
35 pressure increase in the third of said hydraulic lines.

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1 17. An apparatus as recited in Claim 16, further
2 comprising a check valve engaged in series with said
3 pilot operated valve between a hydraulic line and the
4 tool.

15
6 18. An apparatus as recited in any of Claims 12 to 17,
7 wherein said hydraulic lines are further capable of
8 providing fluid pressure to actuate the well tool.

20
10 19. A system for controlling at least three well tools
11 located downhole in a wellbore, comprising:
12 hydraulic pressure means for selectively
13 pressurizing a fluid;

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14 at least two hydraulic lines engaged with said
15 hydraulic pressure means and with each well tool for
16 selectively conveying fluid pressure to each well tool;
17 and

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18 hydraulic control means engaged between each
19 hydraulic line and each well tool, wherein each
20 hydraulic control means is operable in response to
21 selective pressurization of one or more hydraulic lines
22 by said hydraulic pressure means, and wherein operation
23 of a well tool through the pressurization of one
24 hydraulic line displaces fluid which is conveyed
25 through another hydraulic line.

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27 20. A system as recited in Claim 19, further
28 comprising a controller for detecting said displaced
30 fluid conveyed through a hydraulic line during
31 operation of a well tool.

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32 21. A system as recited in Claim 20, wherein said
33 controller is capable of measuring the displaced fluid
34 conveyed through said hydraulic line.

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36 22. A system as recited in any of Claims 19 to 21,

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1 wherein the number of hydraulic lines engaged with said
2 hydraulic pressure means and with each well tool is
3 equal to the number of well tools located downhole in
4 the wellbore.

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6 23. A system as recited in any of Claims 19 to 22,
7 wherein each well tool is uniquely operable by the
8 pressurization of a unique combination of said
9 hydraulic lines.

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11 24. A system as recited in Claim 23, wherein said
12 hydraulic control means prevent operation of other well
13 tools not responsive to the pressurization of said
14 unique combination of hydraulic lines.

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16 25. A system as recited in either Claim 23 or Claim
17 24, wherein said unique combination of pressurized
18 hydraulic lines represents a signature code formed by
19 pressurized and unpressurized hydraulic lines.

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21 26. A system as recited in Claim 25, wherein said
22 pressurized hydraulic lines contain fluid pressure
23 above a selected pressure, and wherein said
24 unpressurized hydraulic lines contain fluid pressure
25 below a selected pressure.

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27 27. A system as recited in either of Claim 25 or Claim
28 26, wherein the selected pressure is the same for at
29 least two hydraulic lines.

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31 28. A system as recited in any of Claims 19 to 27,
32 wherein said hydraulic pressure means is capable of
33 providing hydraulic fluid power to a well tool through
34 one of said hydraulic lines.

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36 29. A system as recited in Claim 28, wherein the well

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1 tool comprises a sliding sleeve.

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3 30. A system as recited in any of Claims 19 to 29,
4 wherein said hydraulic pressure means is capable of
5 reducing hydraulic pressure for a pressurized fluid
6 below a selected pressure, and wherein said hydraulic
7 control means is capable of preventing further movement
8 of the corresponding tool following such pressure
9 reduction.

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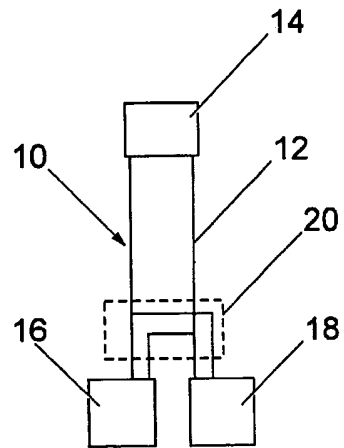


Fig. 1

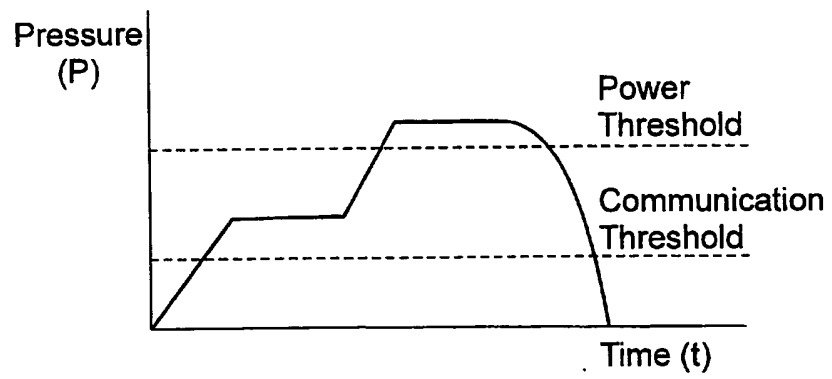


Fig. 2

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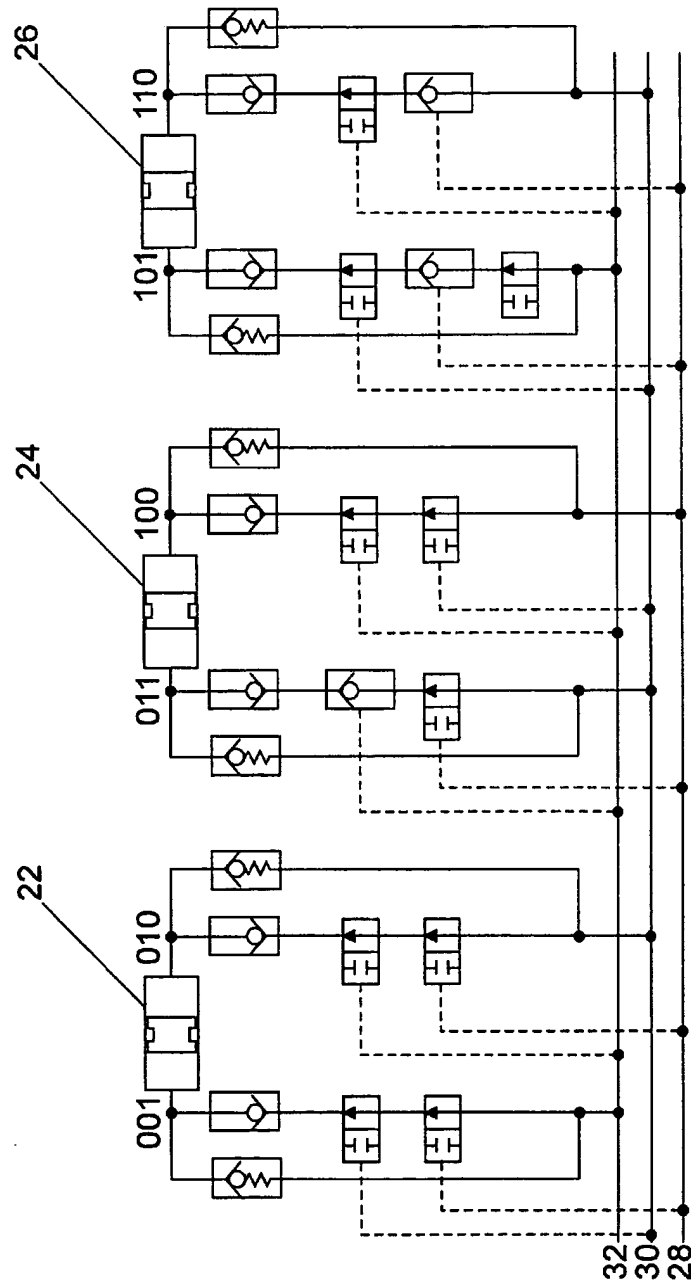


Fig. 3

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A	B	C	ICV
0	0	1	Open 1
0	1	0	Close 1
0	1	1	Open 2
1	0	0	Close 2
1	0	1	Open 3
1	1	0	Close 3

Fig. 4

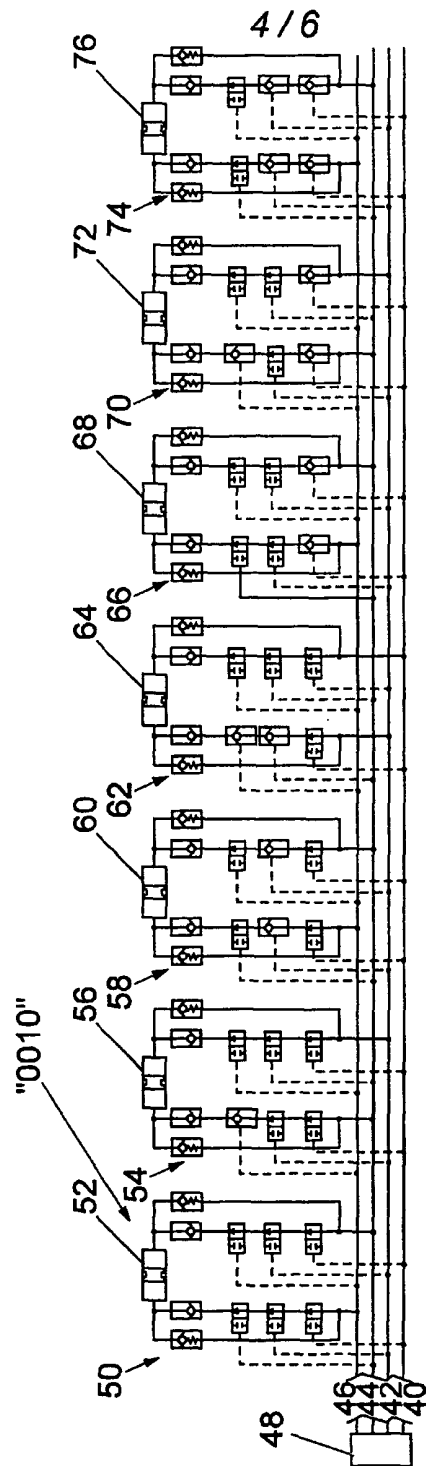


Fig. 5

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A	B	C	D	ICV
0	0	0	1	Open 1
0	0	1	0	Close 1
0	0	1	1	Open 2
0	1	0	0	Close 2
0	1	0	1	Open 3
0	1	1	0	Close 3
0	1	1	1	Open 4
1	0	0	0	Close 4
1	0	0	1	Open 5
1	0	1	0	Close 5
1	0	1	1	Open 6
1	1	0	0	Close 6
1	1	0	1	Open 7
1	1	1	0	Close 7

Fig. 6

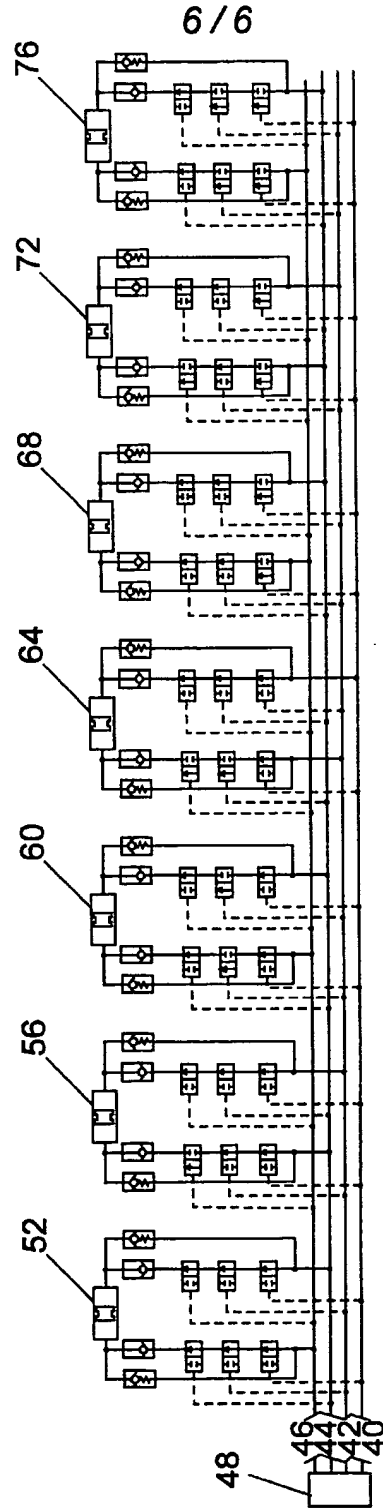


Fig. 7

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 99/02694

A. CLASSIFICATION OF SUBJECT MATTER IPC 7 E21B34/10		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) IPC 7 E21B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 407 183 A (HORN CHARLES E ET AL) 4 October 1983 (1983-10-04) column 2, line 57-62 column 4, line 16 -column 5, line 15 figures 2-4	1, 12, 19
A	US 5 176 164 A (BOYLE WILLIAM G) 5 January 1993 (1993-01-05) column 6, line 2-14 figure 1	1, 12, 19
A	US 3 702 909 A (KRAAKMAN HILLEBRAND JOHANNES J) 14 November 1972 (1972-11-14) the whole document	1, 12, 19
-/--		
<input checked="" type="checkbox"/> Further documents are listed in the continuation of box C. <input checked="" type="checkbox"/> Patent family members are listed in annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document relating to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
25 November 1999		01/12/1999
Name and mailing address of the ISA European Patent Office, P.B. 5616 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl. Fax: (+31-70) 340-3016		Authorized officer Schouten, A

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International Application No

PCT/GB 99/02694

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 945 995 A (THOLANCE MICHEL ET AL) 7 August 1990 (1990-08-07) column 8, line 3-7, 13-32, 44-68 figure 3 ---	1, 12, 19
A	US 4 660 647 A (RICHART JENE A) 28 April 1987 (1987-04-28) figures 1, 2 ---	1, 12, 19
P, A	WO 98 39547 A (PES INC) 11 September 1998 (1998-09-11) abstract page 1, line 5, 6 ---	1, 12, 19
A	US 4 549 578 A (HIBBS DAVID A ET AL) 29 October 1985 (1985-10-29) column 4 figure 1 -----	1, 12, 19

Form PCT/ISA-210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PC./GB 99/02694

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4407183 A	04-10-1983	BR 7905677 A	13-05-1980
		CA 1118342 A	16-02-1982
		EP 0009364 A	02-04-1980
		JP 1186327 C	20-01-1984
		JP 55045998 A	31-03-1980
		JP 58016438 B	31-03-1983
		NO 793095 A	28-03-1980
US 5176164 A	05-01-1993	GB 2239472 A,B	03-07-1991
		US 5172717 A	22-12-1992
US 3702909 A	14-11-1972	NL 7006059 A	27-10-1971
		CA 933436 A	11-09-1973
		DE 2116678 A	18-11-1971
		FR 2086344 A	31-12-1971
		GB 1308091 A	21-02-1973
US 4945995 A	07-08-1990	FR 2626647 A	04-08-1989
		FR 2626614 A	04-08-1989
		CA 1336882 A	05-09-1995
		DE 68928332 D	30-10-1997
		DE 68928332 T	29-01-1998
		DK 38489 A	30-07-1989
		EP 0327432 A	09-08-1989
		NO 180463 B	13-01-1997
		CA 1325368 A	21-12-1993
US 4660647 A	28-04-1987	GB 2179383 A	04-03-1987
		NO 862450 A	24-02-1987
WO 9839547 A	11-09-1998	AU 6672198 A	22-09-1998
		EP 0923690 A	23-06-1999
US 4549578 A	29-10-1985	AU 565981 B	01-10-1987
		AU 4023385 A	26-09-1985
		BR 8501254 A	12-11-1985
		CA 1243584 A	25-10-1988
		DE 3510037 A	26-09-1985
		FR 2561723 A	27-09-1985
		GB 2156105 A,B	02-10-1985
		JP 61002906 A	08-01-1986
		NO 851112 A	23-09-1985
		SE 8501384 A	22-09-1985